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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

FREE-SPINNING AND TUMBLING CHARACTERISTICS OF A $\frac{1}{20}$-SCALE MODEL OF THE DOUGLAS XF4D-1 AIRPLANE AS DETERMINED IN THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL

TED NO. NACA DE 346

By Henry A. Lee

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Langley Air Force Base, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
WASHINGTON

~~CONFIDENTIAL~~

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SUMMARY

An investigation has been conducted in the Langley 20-foot free-spinning tunnel of a $\frac{1}{20}$-scale model of the Douglas XF4D-1 airplane. The erect-spin and recovery characteristics of the model were determined for the normal loading with the model in the clean condition and with slats and dive brakes extended. The spin investigation also included inverted-spin tests and spin-recovery parachute tests. The tumbling tendencies of the model were also investigated.

The results indicated that any fully developed erect spin obtained on the airplane will be satisfactorily terminated if rudder reversal is accompanied by moving the ailerons to full with the spin (stick right in a right spin). Inverted spins should be satisfactorily terminated by full reversal of the rudder, ailerons maintained at neutral. Extension of slats or dive brakes will have no appreciable effect on the spin-recovery characteristics. The model test results indicate that either a 15-foot tail or an 8-foot wing-tip conventional parachute (drag coefficient approximately 0.7) should be effective as an emergency spin-recovery device during demonstration spins of the airplane. The model results indicate that the airplane should not tumble.

INTRODUCTION

In accordance with the request of the Bureau of Aeronautics, Department of the Navy, an investigation was performed in the Langley 20-foot free-spinning tunnel to determine the spin, spin-recovery, and tumbling characteristics of a $\frac{1}{20}$-scale model of the Douglas XF4D-1 airplane. The XF4D-1 airplane has a modified delta-wing plan form with a 52.5° sweptback leading edge and has no horizontal tail.

The erect- and inverted-spin and recovery characteristics and the tumbling characteristics were determined for the normal gross weight with the model in the clean condition. Tests were also made to determine the effects of extending slats and dive brakes and of deflecting trimmers on the spinning and tumbling characteristics of the model. The minimum-size wing-tip and tail parachutes required for emergency recovery from the spin were also determined.

SYMBOLS

b	wing span, feet
S	wing area, square feet
c	wing or elevator chord at any station along span
$\bar{c}$	mean aerodynamic chord, feet
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of distance between center of gravity and fuselage center line to mean aerodynamic chord (positive when center of gravity is below line)
m	mass of airplane, slugs
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-feet^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter

$\frac{I_Y - I_Z}{mb^2}$ inertia rolling-moment parameter

$\frac{I_Z - I_X}{mb^2}$ inertia pitching-moment parameter

ρ air density, slugs per cubic foot

μ relative density of airplane $(m/\rho Sb)$

α angle between fuselage line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), degrees

ϕ angle between span axis and horizontal, degrees

V full-scale true rate of descent, feet per second

Ω full-scale angular velocity about spin axis, revolutions per second

σ helix angle, angle between flight path and vertical, degrees (for the tests of this model, the average absolute value of the helix angle was approximately 4°)

β approximate angle of sideslip at center of gravity, degrees (sideslip is inward when inner wing is down by an amount greater than the helix angle)

APPARATUS AND METHODS

Model

The $\frac{1}{20}$-scale model of the Douglas XF4D-1 airplane was furnished by the Bureau of Aeronautics, Department of the Navy, and was prepared for testing by the Langley Laboratory of the National Advisory Committee for Aeronautics. A three-view drawing of the model as tested is shown in figure 1. A photograph showing the model in the normal flying configuration is shown as figure 2 and a photograph of the model with slats and dive brakes extended is shown as figure 3. Dimensional characteristics of the airplane are presented in table I.

The model was ballasted to obtain dynamic similarity to the airplane at an altitude of 15,000 feet (ρ = 0.001496 slug/cu ft). A remote control mechanism was installed in the model to actuate the controls for the recovery attempts and to open the parachute for the parachute tests. Sufficient moments were exerted on the controls for the recovery attempts to reverse them fully and rapidly.

Lateral and longitudinal controls were combined in one pair of control surfaces called elevons. Longitudinal control was obtained by deflection of the elevons in the same direction and lateral control was obtained by deflection of the elevons differentially. However, in this paper, elevon deflections for longitudinal and lateral control will be referred to, for simplicity, as elevator and aileron deflections, respectively. The model was also provided with small control surfaces called trimmers located at the trailing edge of the wing inboard of the elevons. (See fig. 1.)

Wind Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is generally similar to that described in reference 1 for the Langley 15-foot free-spinning tunnel.

Spin tests.- The launching technique for the model spin tests has been changed from that described in reference 1 in that the model is now launched by hand, with rotation, into the vertically rising air stream. After a number of turns in the established spin, recovery is attempted by moving one or more controls. After recovery the model dives into a safety net. A photograph of the model during a spin is shown as figure 4.

The spin data presented were obtained and converted to corresponding full-scale values by methods described in reference 1. The turns for recovery were measured from the time the controls were moved, or the parachute was opened, to the time the spin rotation ceased and the model dived into the net. For the spins which had a rate of descent in excess of that which can readily be attained in the tunnel, the rate of descent was recorded as greater than the velocity at the time the model hit the safety net, for example, >300. For these tests, the recovery was attempted before the model reached its final steeper attitude and while the model was still descending in the tunnel. Such results are conservative; that is, recoveries will not be as fast as when the model is in the final steeper attitude. For recovery attempts in which the model struck the safety net while it was still in a spin, the recovery was recorded as greater than the number of turns from the time the controls were moved to the time the model struck the net, as >3. A >3-turn recovery does not necessarily indicate an improvement over a >7-turn recovery. For recovery attempts in which the model did not recover, the recovery result was recorded as ∞. When the model recovered without control movement, with the controls with the spin, the results were recorded as "no spin."

Spin-tunnel tests are usually made to determine the spin and recovery characteristics of the model at the normal spinning control configuration (elevator full up, ailerons neutral, and rudder full with the spin) and at various other aileron-elevator control combinations including zero and maximum deflections. Recovery is generally attempted by rapid full rudder reversal. During this investigation, recoveries were also attempted by simultaneous movement of the rudder and ailerons. Tests are also performed to evaluate the possible adverse effects on recovery of small deviations from the normal control configuration for spinning. For these tests, the ailerons are set at one-third of the full deflection in the direction conducive to slower recoveries and the elevator is set at two-thirds of its full-up deflection or full up, whichever is conducive to slower recovery. Recovery is attempted by rapidly reversing the rudder from full with the spin to two-thirds against the spin, by simultaneous rudder and elevator movement, or, as for the present investigation, by simultaneous rudder reversal to two-thirds against the spin and aileron movement to full with the spin. This control configuration and manipulation is referred to as the "criterion spin." Recovery characteristics of the model are considered satisfactory if recovery from this criterion spin requires $2\frac{1}{4}$ turns or less. This value has been selected on the basis of full-scale-airplane spin-recovery data that are available for comparison with corresponding model test results.

For the spin-recovery parachute tests, the minimum-size wing-tip or tail parachute required to effect recovery within $2\frac{1}{4}$ turns from the criterion spin was considered satisfactory. For these tests, the parachute was opened for the recovery attempts by actuating the remote control mechanism and the rudder was held with the spin so that recovery was due entirely to the parachute action alone. For the tail-parachute tests, the towline was attached to the model at the rear of the fuselage just above the jet exhaust and the parachute was packed above the outboard wing (left side in a right spin) on the fuselage area between the base of the rudder and the outboard trimmer. For the model tests, locating the parachute back above the outboard wing did not affect the steady spin. The towline length selected for the tail-parachute tests was obtained from the data presented in reference 2. Wing-tip parachutes were attached to the outer wing tip just in front of the elevon hinge line, the length of the towline being such that when fully extended the parachute just missed the vertical tail. The folded wing-tip parachute was placed on the wing in such a position that it did not seriously influence the established spin. For the model tests, a rubber band holding the packed parachute to the wing or fuselage was released and the parachute was opened merely by the action of the air stream. On the full-scale parachute installation it would be desirable to mount the parachute pack within the airplane structure, and it is recommended that a positive ejection mechanism be employed to open the parachute.

Tumbling tests.- Two methods of launching were employed in determining the susceptibility of the model to tumbling. For one method, the model was held at an attitude approximately 180° to the vertical air stream and was then dropped, thus simulating a whip-stall condition. For the second method of launching, the model was held at approximately 90° to the air stream and then given an initial pitching rotation by hand. The resulting motions were observed and photographed.

If a model tumbles with either method of launching, it is taken as an indication that the corresponding airplane can tumble although the airplane would be more likely to tumble if the model started tumbling when launched with no pitching rotation. If the model stops tumbling after being launched with initial pitching rotation, the results are interpreted to mean that the corresponding airplane definitely will not tumble.

PRECISION

The model test results presented are believed to be true values given by the model within the following limits:

α, degrees	±1
ϕ, degrees	±1
V, percent	±5
Ω, percent	±2
Turns for recovery:	
From motion-picture records	±1/4
From visual observation	±1/2

The preceding limits may have been exceeded for some of the spins in which it was difficult to control the model in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

Comparison between model and full-scale results in reference 3 indicated that model tests satisfactorily predicted full-scale recovery characteristics approximately 90 percent of the time and for the remaining 10 percent of the time the model results were of value in predicting some of the details of the full-scale spins. The airplanes generally spun at an angle of attack closer to 45° than did the corresponding models. The comparison presented in reference 3 also indicated that generally the airplanes spun with the inner wing tilted more downward and with a greater altitude loss per revolution than did the corresponding models. This comparison was made primarily for conventional airplane designs, however, and may not be strictly applicable to the XF4D-1.

Because it is impracticable to ballast the model exactly and because of inadvertent damage to the model during tests, the measured weight and mass distribution of the XF4D-1 model varied from the true scaled-down values within the following limits:

Weight, percent	0 to 3 high
Center-of-gravity location, percent $\bar{c}$	.1 rearward
Moments of inertia:	
I_X, percent	3 low to 2 high
I_Y, percent	0 to 5 high
I_Z, percent	1 low to 3 high

The accuracy of measuring weight and mass distribution is believed to be within the following limits:

Weight, percent	±1
Center-of-gravity location, percent $\bar{c}$	±1
Moments of inertia, percent	±5

Controls were set with an accuracy of $\pm 1^{\circ}$.

TEST CONDITIONS

The mass characteristics and inertia parameters for loadings possible on the airplane and for the loading of the model during the tests are shown in table II and plotted in figure 5. As discussed in reference 4, figure 5 has been used as an aid in predicting the relative effectiveness of the controls on the recovery characteristics of models through a range of loadings. The XF4D-1 loadings, however, are beyond the range of loadings in reference 4, and therefore the control effectiveness of the current design may not be completely predictable by the use of reference 4.

The maximum control deflections (perpendicular to the hinge lines) used in the tests were:

Rudder, degrees	30 right, 30 left
Elevator, degrees	20 up, 15 down
Ailerons, degrees	15 up, 15 down
Trimmers, degrees	30 up, 30 down

Figure 6 shows the angular deflections of the elevons plotted against stick deflection.

In addition to being tested in the clean condition, the model was also investigated with slats fully extended, with dive brakes fully extended, and with both slats and dive brakes extended.

RESULTS AND DISCUSSION

The results of the model spin tests are presented in charts 1 to 6 and in table III. The model data are presented in terms of full-scale values for the airplane at an altitude of 15,000 feet. Similar results were obtained when the model was launched with spinning rotation either to pilot's right or left and therefore all spinning results are arbitrarily presented for rotation to the pilot's right.

Erect Spins

Clean condition, normal loading.- The erect-spin data and the recovery data obtained for the normal loading (loading 7 in table II and fig. 5) with the model in the clean condition and with trimmers neutral are presented in chart 1. When the ailerons were set to neutral or to against the spin (stick left in a right spin) two conditions were generally indicated to be possible: Either the model would not spin or would spin with oscillations in pitch and/or roll. Recoveries from the elevator-up spins by rudder reversal alone were indicated to be either extremely slow or not obtainable at all. Setting the elevator to neutral or down (ailerons at neutral) had a somewhat beneficial effect on the recoveries in that either a satisfactory or an unsatisfactory recovery could be obtained depending on whether the model was in the steep or flat phase of its pitching oscillation, respectively, when the rudder was moved for recovery. When the ailerons were set to with the spin (stick right in a right spin), however, only very steep spins were obtained and recoveries attempted by rudder reversal were now indicated to be very rapid for all elevator settings. Although the type of recovery obtained from the elevator-neutral or elevator-down spins when the ailerons were with the spin was a rapid aileron roll, the model results presented in chart 1 indicate that the roll was quickly terminated by moving the ailerons in a direction to oppose the rolling motion.

To determine if movement of the ailerons or elevators would aid recoveries from the aileron-neutral and aileron-against spins, recoveries were attempted by simultaneously reversing the rudder and elevator and by simultaneously reversing the rudder and moving the aileron to with the spin. The results of these tests, presented in chart 1, show that reversal of the elevator in conjunction with rudder reversal did not always enable the model to recover satisfactorily because of the oscillatory nature of the spin. Although movement of the ailerons to only one-third with the spin in conjunction with rudder reversal did not enable the model to recover satisfactorily from the criterion spin, the data presented in chart 1 indicate that movement of the ailerons to full with the spin in conjunction with rudder reversal would enable the model to recover satisfactorily. These results thus indicate that the ailerons when fully deflected with the spin were an extremely effective control in assisting recovery from a spin.

In the past it has not been a general policy to recommend movement of the ailerons to with the spin to effect recovery because movement of an additional control for recovery may cause a pilot to be somewhat confused, and also because spin-tunnel tests have indicated in the past that a model is generally slow to respond to the aileron movement. For airplanes that have a very great portion of the weight distributed along the fuselage relative to the weight in the wing, as has the XF4D-1, it might be expected that, because of inertia effects, the response of the airplane to aileron movement during spins might be fast and even faster than its response to movement of the rudder or elevator. Thus it would appear that rudder and ailerons instead of rudder and elevator might be the predominant controls in effecting recovery from spins for airplanes that are loaded very heavily along the fuselage. This has been borne out by the model spin test results of the XF4D-1 and other models recently investigated in the spin tunnel that were loaded heavily along the fuselage.

Comparison of the results of tests presented in charts 1 and 2 indicates that deflecting trimmers 30° up or down from neutral had little effect on the model spin or recovery characteristics. It should be noted that the spin-recovery data presented for the aileron-neutral and aileron-against spins in chart 2 and in all subsequent erect-spin charts are for recovery attempted by simultaneous reversal of rudder and movement of ailerons to full with the spin.

<u>Effect of extending slats, dive brakes, and landing gear</u>.- The results of the tests with the slats and dive brakes extended either singly or in combination were similar to those obtained for the clean condition. The results of these tests are presented in charts 3, 4, and 5. Although no specific tests were conducted with the landing gear extended, it would be expected that extension of the landing gear would have little effect on the spin-recovery characteristics on the basis of the analysis presented in reference 5.

<u>Loading variations</u>.- Spin-tunnel experience has indicated that variation in loading through the range possible on XF4D-1 airplane $\left(\frac{I_X - I_Y}{mb^2} = -334 \times 10^{-4}\right.$ to $\frac{I_X - I_Y}{mb^2} = -432 \times 10^{-4}$ and center-of-gravity variation from 21.5 percent to 27 percent of the mean aerodynamic chord$\left.\right)$ should have little effect on the spin and recovery characteristics.

It should be noted that a spin-tunnel investigation of a 60° delta-wing model without a horizontal tail (reference 6) of proportions somewhat similar to the XF4D-1 had indicated that the rate of change in angle of attack from highly stalled attitudes that resulted after termination of spinning rotation to an unstalled angle of attack was quite slow and also that the model indicated a tendency to trim above the stall for rearward positions of the center of gravity. Although the XF4D-1 spin model did not indicate any unusual characteristics in pitch for the center-of-gravity position investigated (approximately 24 percent of the mean aerodynamic chord) it would appear desirable on the basis of the results presented in reference 6 to maintain the center of gravity at as far forward a station as practicable in order to avoid possible trim conditions above the stall.

Inverted Spins

The results of the inverted-spin tests of the model in the design gross weight loading are presented in chart 6. The order used for presenting the data for inverted spins is different from that used for erect spins in that for inverted spins, controls crossed for the established spin (right rudder pedal forward and stick to pilot's left for a spin to pilot's right) is presented to the right of the chart and stick back is presented at the bottom. When the controls are crossed in the established spin, the ailerons aid the rolling motion; when the controls are together, the ailerons oppose the rolling motion. The angle of wing tilt ϕ in the chart is given as up or down relative to the ground.

The model spun inverted at all aileron-elevator configurations when the rudder was with the spin and the results indicate that inverted spins of the full-scale XF4D-1 airplane can be satisfactorily terminated by fully reversing the rudder to against the spin while maintaining the ailerons at neutral.

Spin-Recovery Parachutes

The results of the spin-recovery parachute tests are presented in table III. Either a tail parachute 15 feet in diameter with a towline length equivalent to 20 feet or a wing-tip parachute 8 feet in diameter with a towline length of 6.7 feet (all dimensions full-scale) appears to be necessary for satisfactory recovery from spins by parachute action alone. The parachutes tested were of the flat type having a drag coefficient of approximately 0.7. If a parachute with a different drag coefficient is used, a corresponding adjustment will be required in parachute size. Reference 7 indicates that conventional flat parachutes made of low-porosity materials are unstable and may seriously affect the stability of the airplane in normal flight when the parachute is opened to test its operation. It may be desirable, therefore, to use a stable parachute (reference 7) as an emergency spin-recovery device on the full-scale airplane.

Recommended Spin-Recovery Technique

Based on the results obtained with the model, the following recommendations are made as to recovery technique for all loadings and conditions of the airplane:

For erect spins, the rudder should be reversed briskly from full with the spin to full against the spin accompanied by simultaneous lateral movement of the stick to full with the spin; after the spin rotation has ceased the stick should be neutralized laterally and moved forward to regain normal flight. If the stick is moved forward prematurely, that is, before the spin rotation ceases, a rapid aileron roll may result; however, this roll can be terminated rapidly by movement of the ailerons to oppose the rolling motion.

For recovery from inverted spins the rudder should be reversed briskly to full against the spin and the ailerons should be maintained at neutral.

Tumbling Tests

The tumbling tests were conducted with the model in the normal gross weight loading (center of gravity at 24 percent $\bar{c}$) with the ailerons and rudder at neutral. The results of these tests (not presented in tabular form) showed that the model had no tendency to tumble at any elevator setting or for any model configuration (slats and dive brakes extended or retracted or trimmers deflected or neutralized). When launched with forced pitching rotation the tumbling imparted to the model was damped out after about 1 to 2 turns and a pitching oscillation encountered by the model after the tumbling had ceased was damped out rapidly. When launched from a whip-stall attitude the model pitched its nose downward and oscillated in pitch for a short period before diving out. Although these tests were conducted with the center of gravity at approximately 24 percent of the mean aerodynamic chord, the tumbling criterion charts presented in reference 8 indicate that the model would still resist tumbling with the center of gravity moved to the most rearward position obtainable on the XF4D-1 airplane (27 percent of the mean aerodynamic chord).

CONCLUSIONS

Based on the results of tests of a $\frac{1}{20}$-scale model of the Douglas XF4D-1 airplane, the following conclusions regarding the spin and recovery characteristics and the tumbling tendencies of the airplane at an altitude of 15,000 feet are made:

1. The spin-recovery characteristics of the airplane will be satisfactory for all loadings if the following technique is used: Brisk rudder reversal and simultaneous movement of the ailerons to full with the spin (stick right in a right spin); after the spin rotation ceases the stick should be neutralized laterally and moved forward longitudinally to regain normal flight.

2. Extending the slats or dive brakes will have little effect on the spin or recovery characteristics.

3. Either a 15-foot-diameter (laid out flat) tail parachute or an 8-foot-diameter wing-tip parachute having a drag coefficient of approximately 0.7 will be effective for emergency recovery from demonstration spins.

4. Satisfactory recovery from inverted spins will be obtained by full reversal of the rudder, ailerons being maintained at neutral.

5. The airplane will not tumble for any center-of-gravity position within the design range.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE DOUGLAS XF4D-1 AIRPLANE AS SIMULATED ON THE $\frac{1}{20}$- SCALE SPIN MODEL

Length, over-all, ft	43.67
Wing:	
Span, ft	33.5
Area, sq ft	557
Airfoil section and thickness (percent chord):	
Root chord	NACA 0007-63/30-9.5° modified
Tip chord	NACA 0004-5 63/30-9.5° modified
Mean aerodynamic chord, in.	219
Leading edge $\bar{c}$ behind leading apex angle of wing, in.	107.2
Tip chord, in.	100
Root chord, in.	301
Incidence, deg	0
Dihedral, deg	0
Taper ratio	0.33
Effective aspect ratio	2
Distance from normal center of gravity to intersection of elevon hinge line and fuselage center line, in.	116.08
Distance from normal center of gravity to intersection of rudder hinge line and fuselage center line, in.	140.32
Sweepback of leading edge of wing, deg	52.5
Elevon:	
Span, ft	11.17
Chord behind hinge line (constant), in.	26.0
Area of elevon aft of hinge line (total), sq ft	45.17
Vertical tail:	
Height (from fuselage reference line), ft	10.0
Total area, sq ft	47.7
Rudder area aft of hinge line, sq ft	12.7
Aspect ratio	1.2
Sweepback of leading edge of fin, deg	56.5

TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADINGS POSSIBLE ON THE DOUGLAS XF4D-1 AIRPLANE AND FO
LOADING TESTED ON THE 1/20-SCALE MODEL

[Model values are given as corresponding full-scale values; moments of inertia are given about the center of gra

No.	Loading condition			Weight (lb)	Center-of-gravity location		Relative density μ		Moments of inertia (slug-ft^2)			Mass
					$x/\bar{c}$	$z/\bar{c}$	Sea level	15,000 ft	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$
	Airplane values											
1	Design flight gross weight	Nose heavy	Gear up	15,093	0.215	0	10.56	16.79	9,796	31,537	40,160	-413×10^{-4}
2		Tail heavy	Gear up	15,093	.265	0	10.56	16.79	9,796	31,714	40,336	-417
3	Design landing gross weight	Nose heavy	Gear down	14,517	.235	0.012	10.16	16.15	9,929	31,707	39,874	-431
4		Tail heavy	Gear down	14,517	.270	.009	10.16	16.15	9,959	31,831	39,968	-432
5	Design catapult gross weight	Nose heavy	Gear down	17,657	.240	.008	12.36	19.65	12,167	32,733	43,031	-334
6		Tail heavy	Gear down	17,657	.255	.008	12.36	19.65	12,167	32,721	43,019	-334
7	Normal		Gear up	16,821	.236	0	11.77	18.72	10,346	31,492	40,630	-361
8			Gear down	16,821	.240	0.008	11.77	18.72	10,657	31,657	40,479	-358
	Model values at end of test											
7	Normal		Gear up	17,357	0.241	0.001	12.15	19.31	11,036	34,626	43,743	-374×10^{-4}

TABLE III.- SPIN-RECOVERY-PARACHUTE DATA OBTAINED WITH

A $\frac{1}{20}$-SCALE MODEL OF THE DOUGLAS XF4D-1 AIRPLANE

[Normal loading (loading 7 in table II and fig. 5); rudder fixed full with the spin and recovery attempted by opening the parachute only; model values converted to corresponding full-scale values; C_D of parachutes ≈ 0.7; right erect spins]

Parachute diameter (ft)	Towline length (ft)	Ailerons	Elevator	Turns for recovery
Tail parachutes				
15.0	20.0	Neutral	Full up	$1, \frac{1}{2}, \frac{3}{4}, 2, \frac{1}{2}$
15.0	20.0	$\frac{1}{3}$ against	$\frac{2}{3}$ up	$\frac{3}{4}, \frac{3}{4}, 1\frac{1}{4}, \frac{3}{4}$
13.3	20.0	$\frac{1}{3}$ against	$\frac{2}{3}$ up	$1, 1\frac{1}{4}, 2\frac{3}{4}, 1\frac{1}{2}, 3$
Wing-tip parachutes				
8.0	6.7	Neutral	Full up	$1, 1, \frac{1}{2}, 1$
8.0	6.7	$\frac{1}{3}$ against	$\frac{2}{3}$ up	$2, \frac{1}{2}$
6.7	6.7	Neutral	Full up	$1, 1\frac{1}{4},$ [a]$>3, \frac{1}{2}, >2$

[a]Visual estimate.

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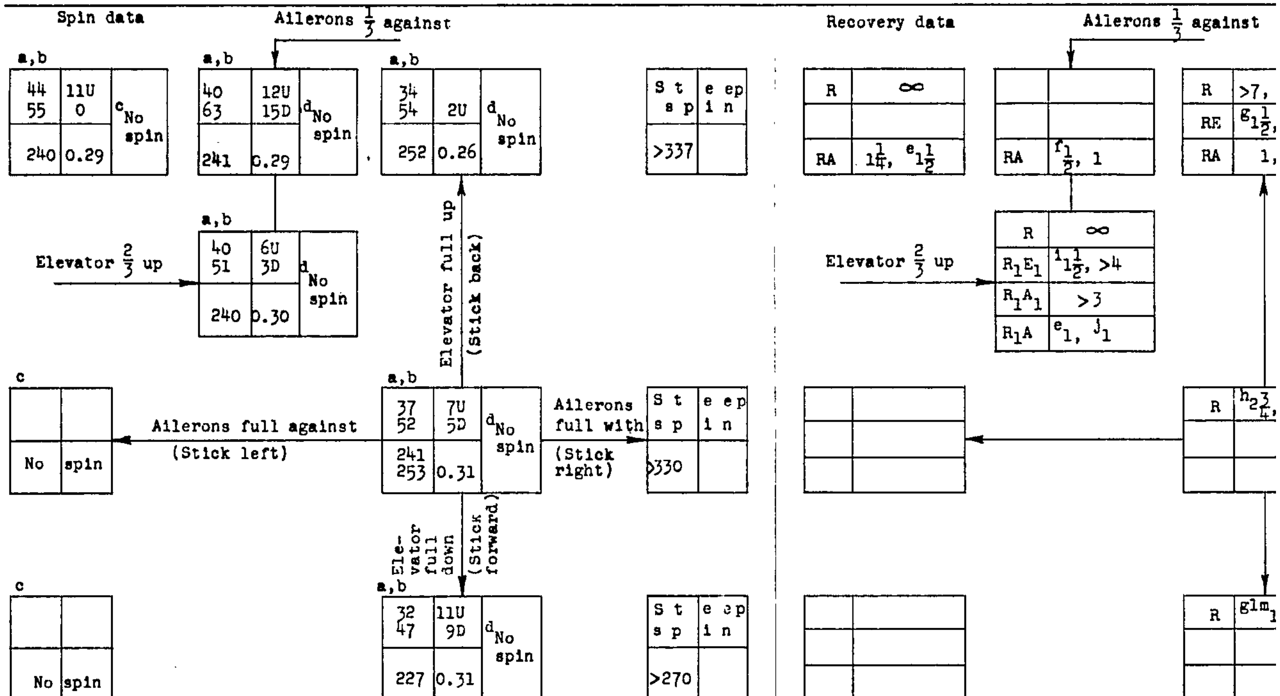
CHART 1.- ERECT-SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE MODEL OF THE DOUGLAS XF4D-1 AIRPLANE

[Normal loading (model loading 7 in table II and figure 5); cockpit closed; trimmers neutral; slats and dive brakes retracted; recovery attempted by rapid control movement as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); right erect spins]



[a]Two conditions possible.
[b]Oscillatory spin. Range of values or average values given.
[c]Model motion becomes increasingly oscillatory in roll and yaw until model rolls over inverted. After going inverted model either rolls in the direction of the aileron setting or dives inverted.
[d]Model motion becomes increasingly oscillatory in pitch, roll, and yaw until model pitches out.
[e]Model recovered in wide radius spiral.
[f]On recovery model went into left spin.
[g]Recovery attempted while model was in steep phase of pitching oscillation.
[h]Recovery attempted while model was in flat phase of pitching oscillation.
[i]Model recovered in inverted glide.
[j]On recovery model went slightly inverted and did rapid aileron roll to right.

α (deg)	ϕ (deg)
V (fps)	Ω (rps)

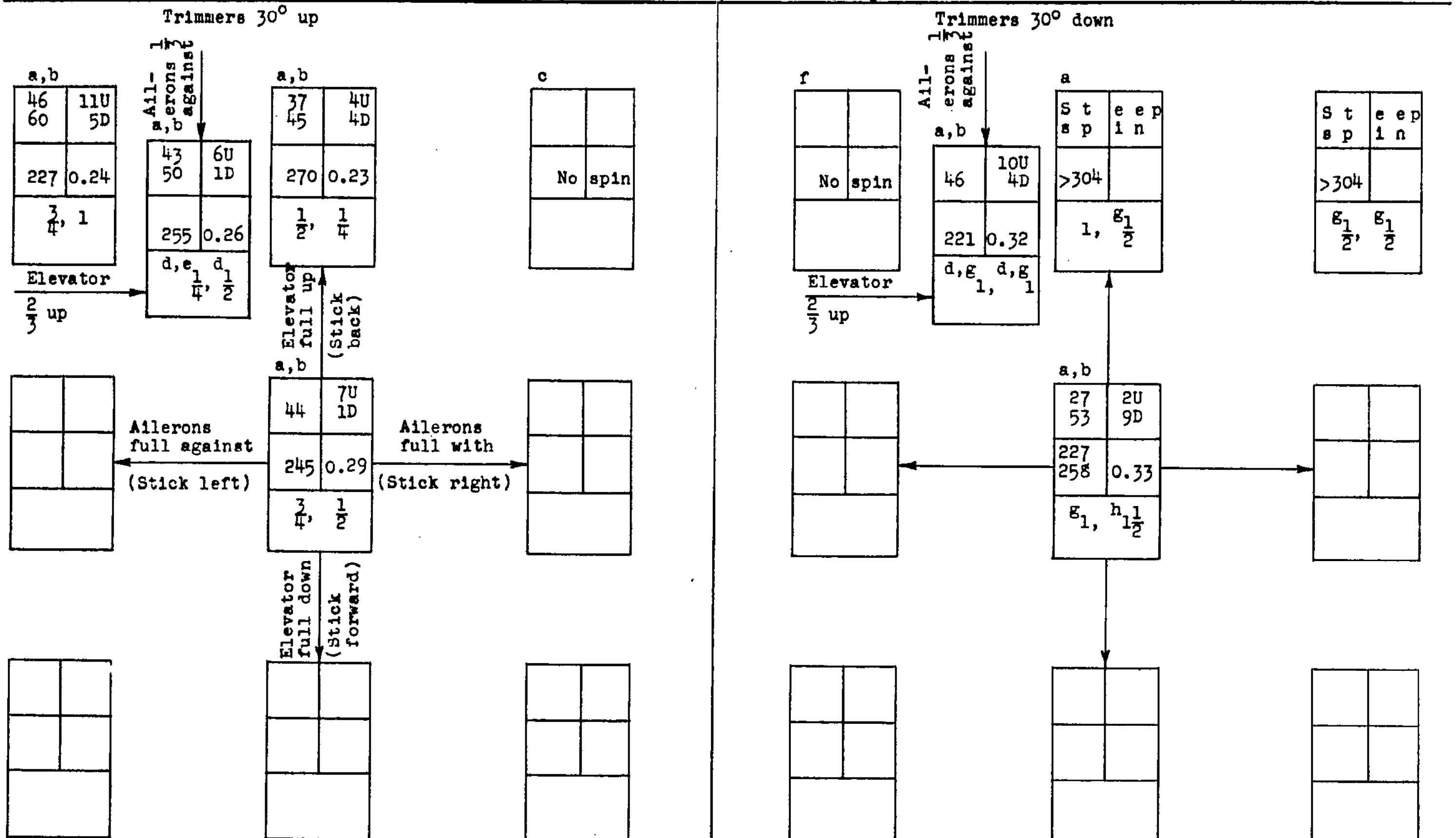
Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

[k]Model recovered in aileron roll to left.
[l]Model recovered in inverted dive.
[m]Visual estimate.
[n]Model went into inverted spin to pilot's right.

Rec
R (Rud aga
R_1 (Rud aga
A (Ail
A_1 (Ail
A_2 (Ail aga
E (Ele dow
E_1 (Ele

CHART 2.- ERECT-SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE MODEL OF THE DOUGLAS XF4D-1 AIRPLANE WITH THE TRIMMERS DEFLECTED

[Normal loading (model loading 7 in table II and figure 5); cockpit closed; slats and dive brakes retracted; recovery attempted by moving ailerons to full with the spin simultaneously with rapid full rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); right erect spins]



[a]A "No spin" condition also obtained.
[b]Oscillatory spin. Range of values or average values given.
[c]After launching rotation expended, model came out in glide.
[d]Recovery attempted by reversing rudder to 2/3 against the spin and simultaneously moving ailerons to full with the spin.
[e]On recovery model went into left spin.
[f]Model motion becomes increasingly oscillatory in roll and yaw until model rolls over inverted. After going inverted model either rolls in the direction of the aileron setting or dives inverted.
[g]Model recovered in vertical aileron roll.
[h]Model recovered in inverted dive.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

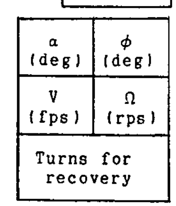
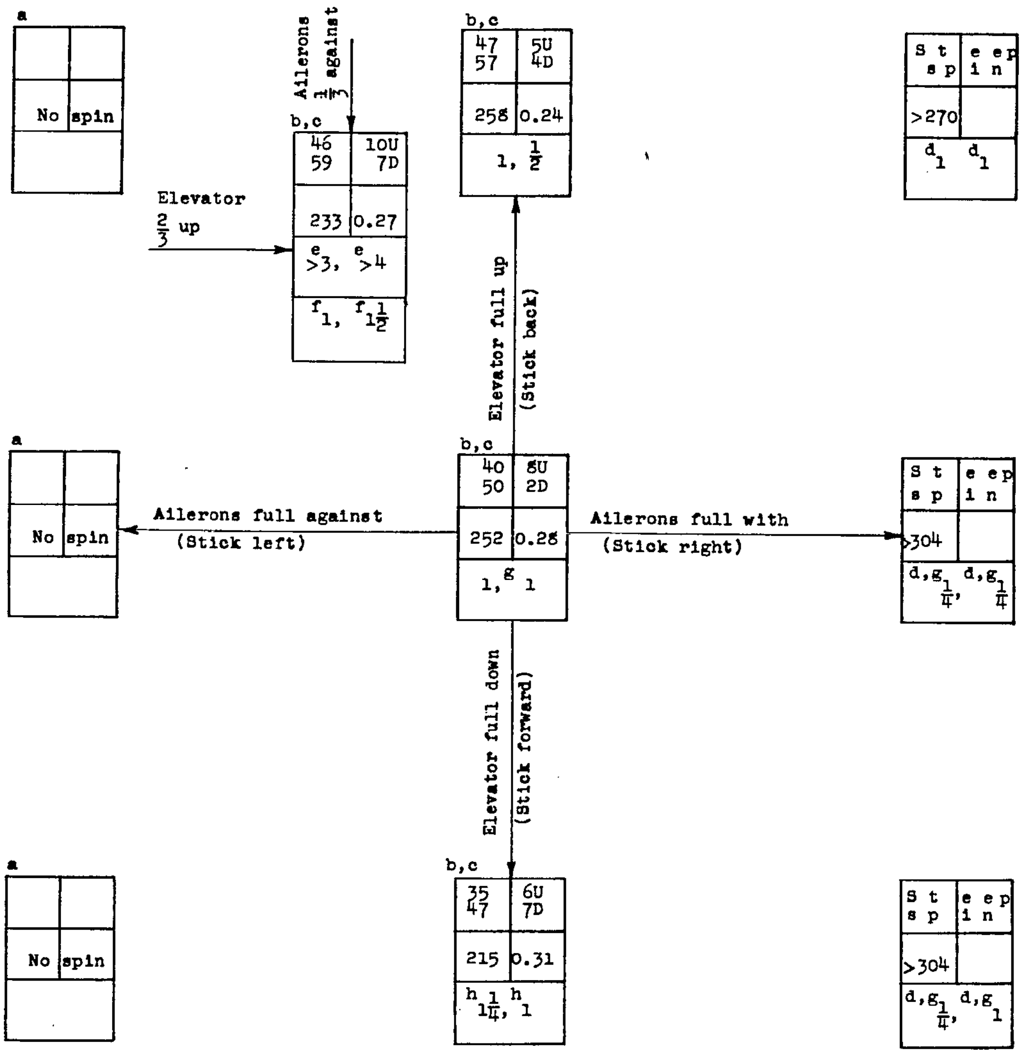


CHART 3.- ERECT-SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE MODEL OF THE DOUGLAS XF4D-1 AIRPLANE WITH THE WING SLATS EXTENDED

[Normal loading (model loading 7 in table II and figure 5); cockpit closed; trimmers neutral; dive brakes retracted; recovery attempted by moving ailerons to full with the spin simultaneously with rapid full rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); right erect spins]



[a]Model motion becomes increasingly oscillatory in roll and yaw until model rolls over inverted. After going inverted model either rolls in the direction of the aileron setting or dives inverted.
[b]Oscillatory spin. Range of values or average values given.
[c]A "No spin" condition also obtained.
[d]Recovery attempted by full rudder reversal only.
[e]Recovery attempted by reversing rudder to 2/3 against the spin and simultaneously moving ailerons to 1/3 with the spin.
[f]Recovery attempted by reversing rudder to 2/3 against the spin and simultaneously moving ailerons to full with the spin.
[g]Model recovered in rapid vertical aileron roll.
[h]Model recovered in inverted dive.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

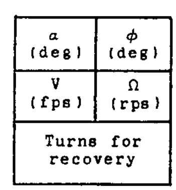


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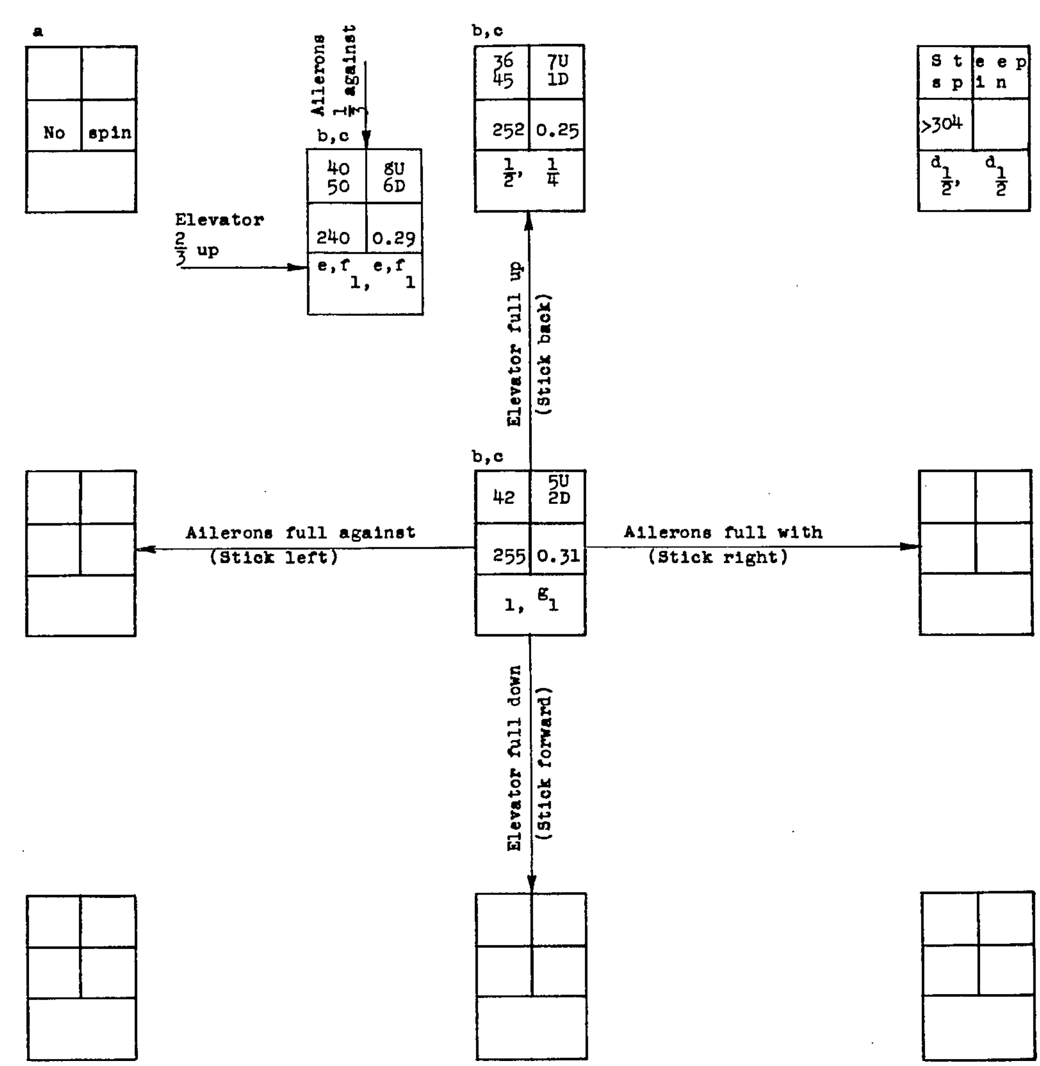
CHART 4.- ERECT-SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE MODEL OF THE DOUGLAS XF4D-1 AIRPLANE WITH THE DIVE BRAKES EXTENDED

[Normal loading (model loading 7 in table II and figure 5); cockpit closed; trimmers neutral; slats retracted; recovery attempted by moving ailerons to full with the spin simultaneously with rapid full rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); right erect spins]



[a]Model motion becomes increasingly oscillatory in roll and yaw until model rolls over inverted. After going inverted model either rolls in the direction of the aileron setting or dives inverted.
[b]Oscillatory spin. Range of values or average values given.
[c]A "No spin" condition also obtained.
[d]Recovery attempted by full rudder reversal only.
[e]Recovery attempted by reversing rudder to 2/3 against the spin and simultaneously moving ailerons to full with the spin.
[f]Model recovered in wide radius spiral.
[g]Model recovered in rapid vertical aileron roll.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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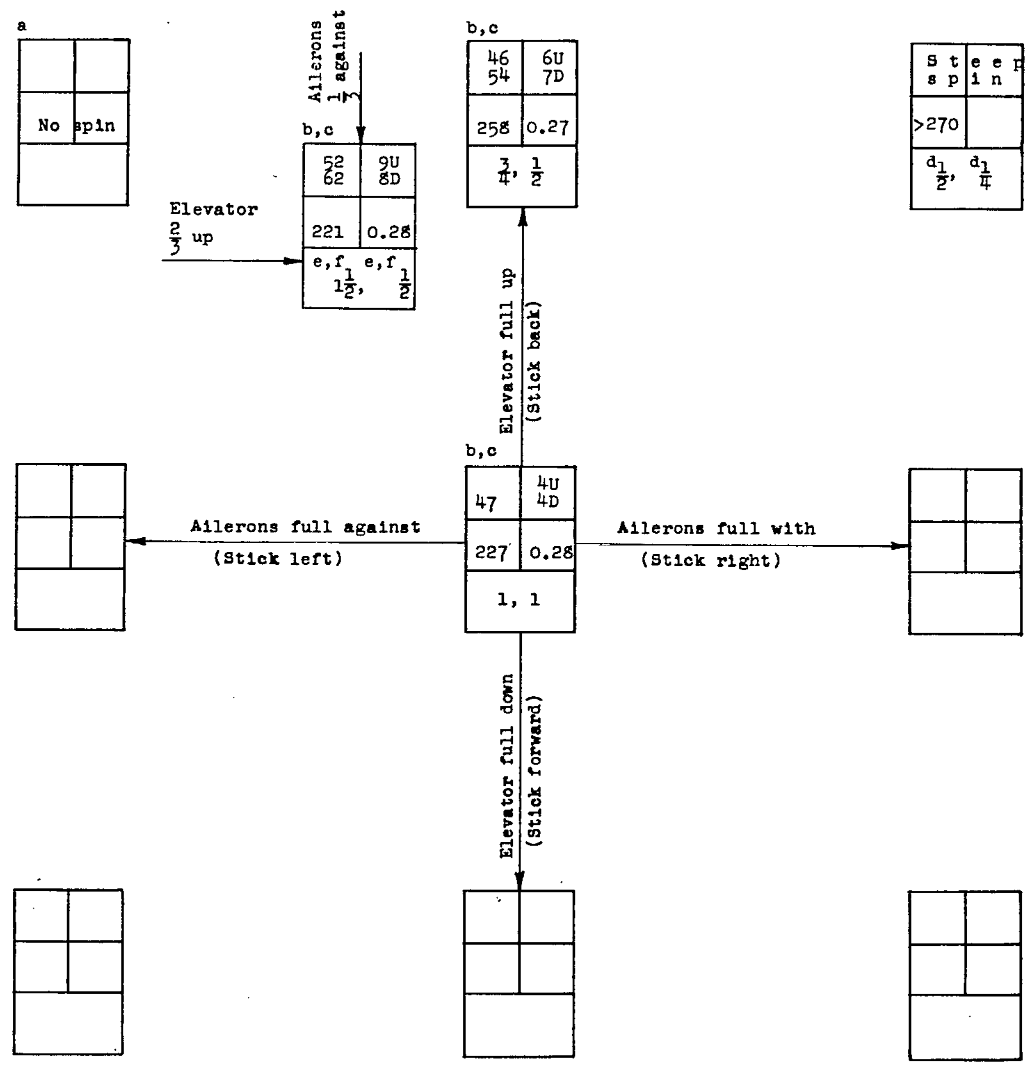
CHART 5.- ERECT-SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE MODEL OF THE DOUGLAS XF4D-1 AIRPLANE WITH THE WING SLATS AND DIVE BRAKES EXTENDED

[Normal loading (model loading 7 in table II and figure 5); cockpit closed; trimmers neutral; recovery attempted by moving ailerons to full with the spin simultaneously with rapid full rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); right erect spins]



[a]Model motion becomes increasingly oscillatory in roll and yaw until model rolls over inverted. After going inverted model either rolls in the direction of the aileron setting or dives inverted.

[b]A "No spin" condition also obtained.

[c]Oscillatory spin. Range of values or average values given.

[d]Recovery attempted by full rudder reversal only.

[e]Recovery attempted by reversing rudder to 2/3 against the spin and simultaneously moving ailerons to full with the spin.

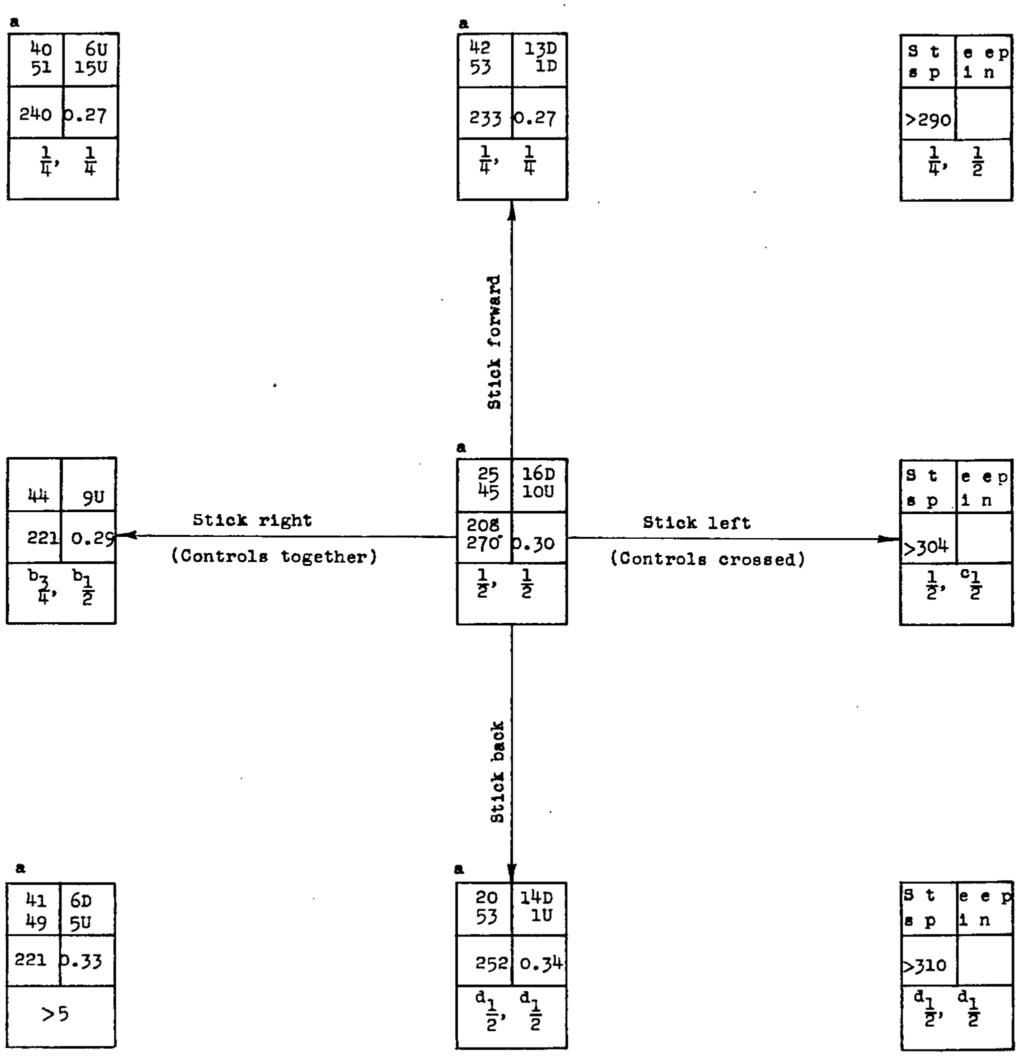
[f]Model recovered in steep wide radius spiral.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

CHART 6.- INVERTED-SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE MODEL OF THE DOUGLAS XF4D-1 AIRPLANE

[Normal loading (model loading 7 in table II and figure 5); cockpit closed; trimmers neutral; slats and dive brakes retracted; recovery attempted by rapid full rudder reversal (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); spins to pilot's right]



[a]Oscillatory spin. Range of values or average values given.
[b]Model recovered in an erect aileron roll to right.
[c]Model recovered in an erect aileron roll to left.
[d]Model recovered in erect glide.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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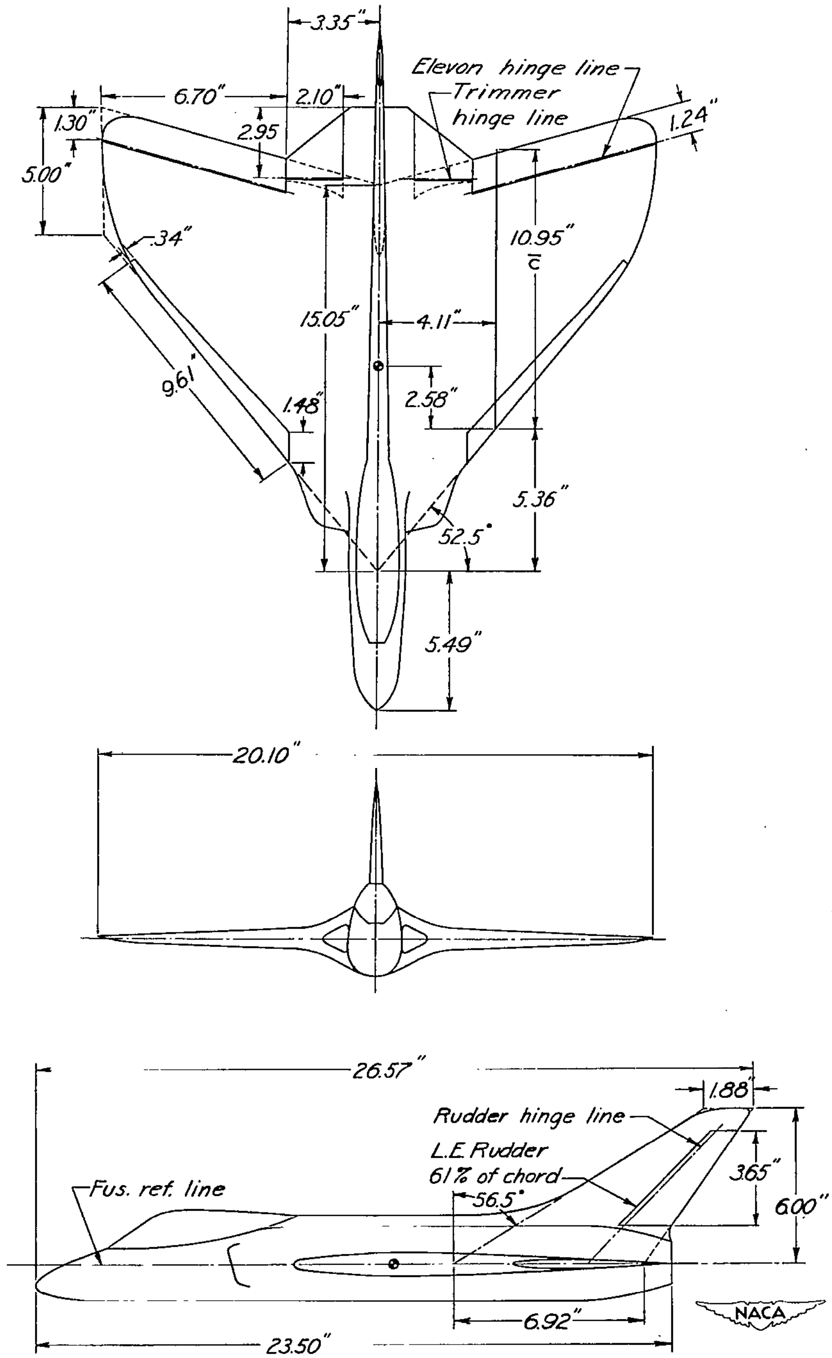

Figure 1.- Three-view drawing of the $\frac{1}{20}$-scale model of the Douglas XF4D-1 airplane as tested in the Langley 20-foot free-spinning tunnel. Dimensions are model values. Center-of-gravity position shown is for the normal gross weight condition.

[redacted]

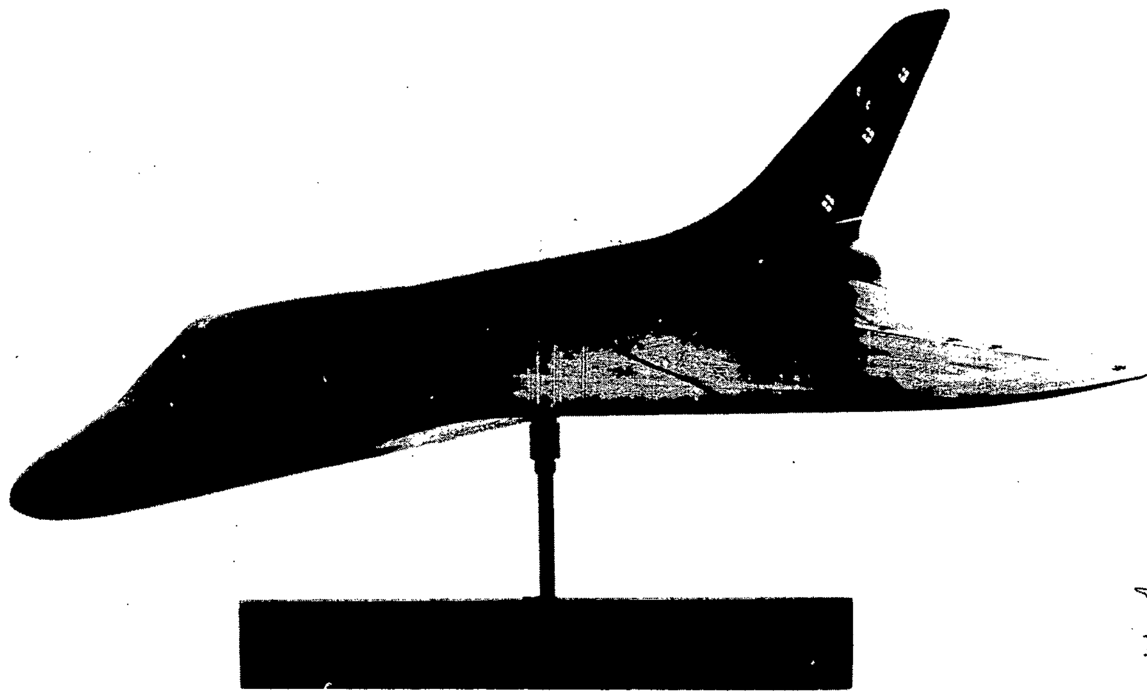

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Figure 2.- The $\frac{1}{20}$-scale model of the Douglas XF4D-1 airplane in the normal-loading clean condition.

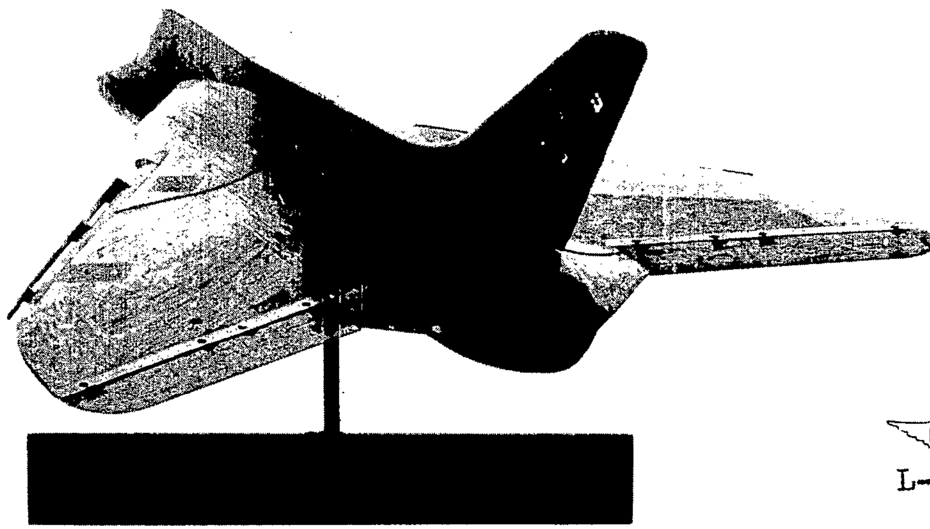

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Figure 3.- The $\frac{1}{20}$-scale model of the Douglas XF4D-1 airplane with leading-edge slats and dive brakes extended.

Figure 4.- The $\frac{1}{20}$-scale model of the Douglas XF4D-1 airplane spinning in the Langley 20-foot free-spinning tunnel.

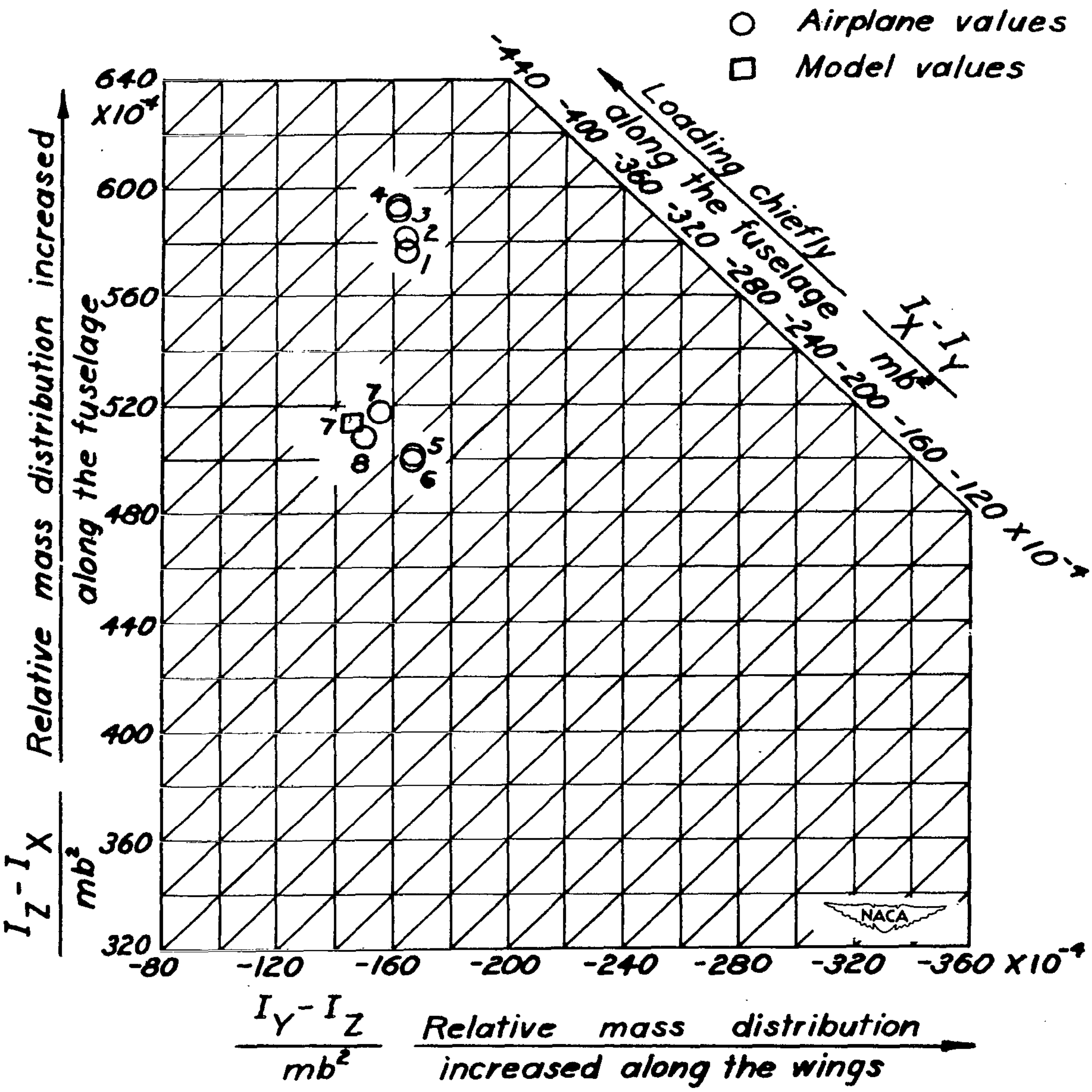

Figure 5.- Mass parameters for loadings possible on the Douglas XF4D-1 airplane and for the loading tested on the $\frac{1}{20}$-scale model. (Points correspond to numbered loadings in table II.)

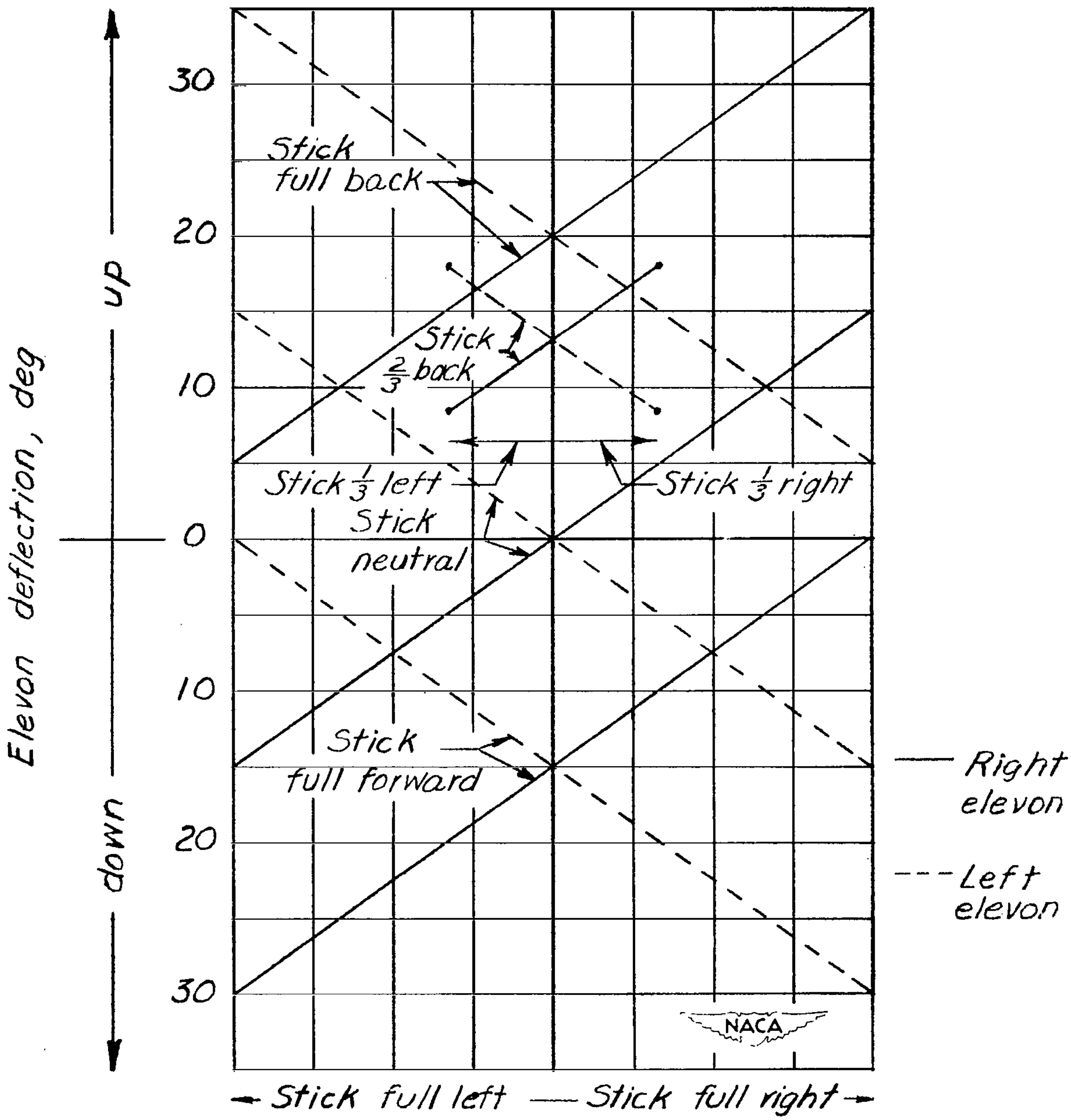

Figure 6.- Elevon deflections used on the $\frac{1}{20}$ - scale model of the Douglas XF4D-1 airplane for various control-stick positions.